PATENT

REMARKS

The Examiner has objected to the specification due to the deficiencies in Equations E2 on page 6 of the current application. Accordingly, Equation E2 has been amended as specified above on page 2 of the current response. Thus, the Applicant respectfully submits to the Examiner that the objection should be withdrawn in view of the amendment to the specification.

The Examiner has rejected claims 2 through 01, 12, 13, 15 through 18 and 20 through 24 under 35 U.S.C. §112, Second Paragraph as allegedly being indefinite for failing to particularly point out and distinctly claim the subject matter which the Applicant regards as the invention.

Accordingly, claim 2 has been amended to now explicitly recite "in the propagation direction."

Claims 6, 8, 15 through 18 and 20 through 24 have been amended to delete the language, "any one of."

Claims 6, 8, 16, 18, 22 and 24 have been amended to recite "polynomial approximation" in lieu of "other mathematical approximation."

Claims 7, 17 and 23 have been amended so that equations E2 now recite "$z >= z_k$" in stead of "$z <= z_k$" Unfortunately, the above amendment in the equations is not indicated in terms of underline and striking since the equation editor lacks such capabilities. Claims 7, 17 and 23 have been further amended to delete "and R is the radius of the curvature of the phase front."

Claim 12 is now directed to "arrayed waveguide grating."

Claim 13 is now amended to explicitly recite "in the coupling region…."

Based upon the above amendments, the Applicant respectfully submits to the Examiner that the rejections under the section 112, Second Paragraph should be withdrawn.

For the prior art rejections, the Examiner has rejected claims 1, 2, 4/1, 4/2, 9/1, 9/2, 14, 19 and 20 under 35 U.S.C. §102(b). Furthermore, the Examiner has rejected claims 4/1, 4/2, 11, 12, 14, 19 and 20 35 U.S.C. §103. To overcome the above pending prior art rejections, the subject matter limitations of dependent claim 4 has been incorporated into independent claim 1.

The same subject matter limitations are already recited in other independent claims 14 and 19. Thus, the same following remarks are applicable to all of the independent claims.

With regard to present claim 4 and European patent application 0 598 622 (Arii), the Examiner states that "The discussion of light leakage of the curved and tapered waveguides in Arii et al implies that at least some of the waveguides in the coupling region have a width that is less than a critical width of the waveguide at a given wavelength" (sentence bridging pages 4 and 5 of the Office Action).

First of all, it is observed that the coupling region according to Arii does not comprise "a plurality of coupled waveguides" as explicitly recited in independent claim 1. Arii relates to "an optical circuit in which a plurality of branched optical waveguides are connected to the light receiving side and the light ejecting side of a main optical waveguide, which mixes the entering light" (claim 1 on page 15 of Arii). Only the main optical waveguide mixes light and qualifies as a coupling region in the sense of the present invention. With reference to the drawings, the coupling region according to Arii (numeral 32 in Figure 2A) extends between the lines marked L1. This region does not comprise "a plurality of coupled waveguides". For this reason alone, (present and former) claim 1 is not anticipated by Arii.

Second, the fact that light leakage is being discussed in Arii does not in the least bit imply that any waveguides having a width smaller than the critical width are present. As explained in Arii (page 5, lines 29-33): "In the process of the propagation of light within an optical waveguide, transmission loss occurs due to the absorption or scattering of light. Transmission loss is determined according to the materials or manufacturing methods of the optical waveguide, and is substantially proportional to the length of the optical waveguide. Accordingly, it is necessary to shorten the dimensions of the optical circuit as much as possible in order to reduce transmission loss." Arii goes on to discuss in detail several specific sources of loss, in particular shape loss, connection loss, and loss due to bend. (Page 5, line 56 to page 6, line 1:) "Reduction of the loss due to bend is a very important issue for waveguide type optical star couplers,

especially for multiple branched optical star couplers. The reason is that in the multiple branched optical star coupler, the degree of bend becomes larger as the position of branched optical waveguides moves toward the outside of the central axis of the mail optical waveguide." Arii then discloses, at great length, specific ways of avoiding losses.

From these extensive discussions, it follows unequivocally that the widths of the branched optical waveguides in Arii are significantly larger than the critical width. For, if these widths would be smaller than the critical width, all the above measures to reduce losses would be futile. Put differently, it is reasonable to conclude that Arii actually teaches away from the present invention, i.e. losses in the branched waveguides should be reduces as much as possible and it is therefore imperative to employ widths larger than the critical width.

Third, one of the inventors, Mr. K. Steenbergen, has calculated the critical width of the waveguides according to Arii based on the data provided on page 6, lines 46-67 of Arii. The above calculations are shown in a graph that is enclosed in the current response. From these calculations, it appears that the critical width of the branched waveguides according to Arii amounts to approximately 1 μm, whereas the actual widths range from 8 to 42 μm (see charts 1 and 2 on pages 13 and 14 of Arii). I.e. the smallest width according to Arii is eight times larger than the critical width.

In view of the above facts, Arii is considered not relevant for amended claim 1 and claim 14.

With regard to the present claim 4 and Tanaka et al, the Examiner mentions that Tanaka et al "states that there is scattering loss in the variable width coupling region waveguides (see Table 1), even though such a loss is less than in the prior art devices. A person of ordinary skill in the art would obviously interpret this data to mean that at least some of the waveguides in the coupling region have a width that is less than a critical width of the waveguide at a given wavelength".

As explained with regard to Arii, scattering losses occur invariably and the fact that such losses are mentioned hence does not imply any information with regard to their source. As these losses should be kept low, it is imperative to employ a width significantly larger than the critical width.

Tanaka relates to glass waveguide 1xN branching devices, comprising a tree configuration of Y-shape branches to split input optical power equally to N output ports, i.e. a 1x8 branching device comprises (1+2+4=) 7 Y-shape branches. An example of a Y-shape branch is shown in Figure 1 of Tanaka.

It is explained in Tanaka (on page 1, left column, last paragraph) that "..., we have found that the difference in the effective refractive index between the waveguide branching region and the substrate is 43% larger than that between the straight waveguide region and the substrate. It has also been calculated that this change in the effective refractive index difference causes large scattering loss. This increase of the effective refractive index is caused by larger amount of ions doped through the wide opening of the conventional Y-shape mask pattern. Therefore we modified the Y-shape mask pattern to be narrower and have smaller branching angle in order to avoid the large and rapid effective refractive index change as shown in Fig.1 (b). Simulation result shows that it is possible to determine the dimension parameters of the modified Y-pattern so as to eliminate the effective refractive index change in the branching region."

Although Tanaka does not mention dimensions or refractive indices, and hence does not allow calculation of the critical width, it is at least likely that the width of the input waveguide of the Y-branch of Tanaka is considerably larger than the critical width, because otherwise losses in this waveguide would be unacceptable.

Mr. K. Steenbergen has performed a literature search and has found Seki et al, "Two-step purely thermal ion-exchange technique for single-mode waveguide devices in glass." A copy of this reference is enclosed in the response for the Examiner's convenience. This article was

drafted by the same research group as Tanaka - Seki is one of the authors of Tanaka, and all authors mentioned in both articles are with the Tsukuba Research Laboratory of the Nippon Sheet Glass Co. - and relates to the same technology, i.e. two-step thermal ion-exchange (see the title of Seki and item 2.1, second paragraph of Tanaka).

Seki mentions, in the right column, lines 21-26, a waveguide having a cross-section of 16 x 9 μm and a contrast of 0.004. It is also noted that this cross-section and contrast yield a modal width that is ideally suited connection to a single mode optical fiber and that the waveguides according to Tanaka are indeed intended for connection to single mode optical fibers (see e.g. page 889 item 3(1) and Fig. 6 of Tanaka).

In view of these facts, it is practically certain (and definitely "more likely than not") that the waveguides in Tanaka also have a cross-section of 16 x 9 μm and a contrast of 0.004. Mr. K. Steenbergen has calculated the critical width of these waveguides for both wavelengths mentioned in Tanaka, i.e. 1300 and 1550 nm. These calculations are shown in the graphs that are also enclosed in the current response.

From these calculations, it appears that the critical width of the branched waveguides according to the Examples in Arii amounts to approximately 4 μm, whereas the actual width is 16 μm. The calculations also show that the 43% and 29% increases of the effective refractive index mentioned in Tanaka result in a decrease of the critical with. I.e. the actual width according Tanaka is at least four times larger than the critical width.

The above conclusions are also confirmed by the fact that in Tanaka use was made of a <u>tree</u> configuration of (1+2+4=7) Y-shape branches, which is bulky and expensive. If use was made of branches having a width smaller than the critical width, a true 1x8 branch device could have been build.

Base upon the above discussions, the Applicant respectfully submits to the Examiner that the pending rejection of newly amended claim 1 and other independent claim 14 and 19 should be withdrawn. Since dependent claims ultimately depend from one of these independent claims and incorporated the above distinguished subject matter limitations, these dependent claims are also patentably distinct.

Conclusion

In view of the above amendments and the foregoing remarks, Applicant respectfully submits that all of the pending claims are in condition for allowance and respectfully request a favorable Office Action so indicating.

Respectfully submitted,

Date: February 3, 2004

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Enclosures:
*Waveguide Description in EP 0 598 622 A1; Inventor: Arii; pg. 1
*Two-Step Purely Thermal Ion-Exchange Technique for Single-Mode Waveguide Devices in Glass; pp. 1258 and 1259 of Electronics Letters 29th September 1988 Vol. 24, No.: 20
*Glass Waveguide 1xN Branching Devices, Tanaka et. Al; pp. 2 and 3

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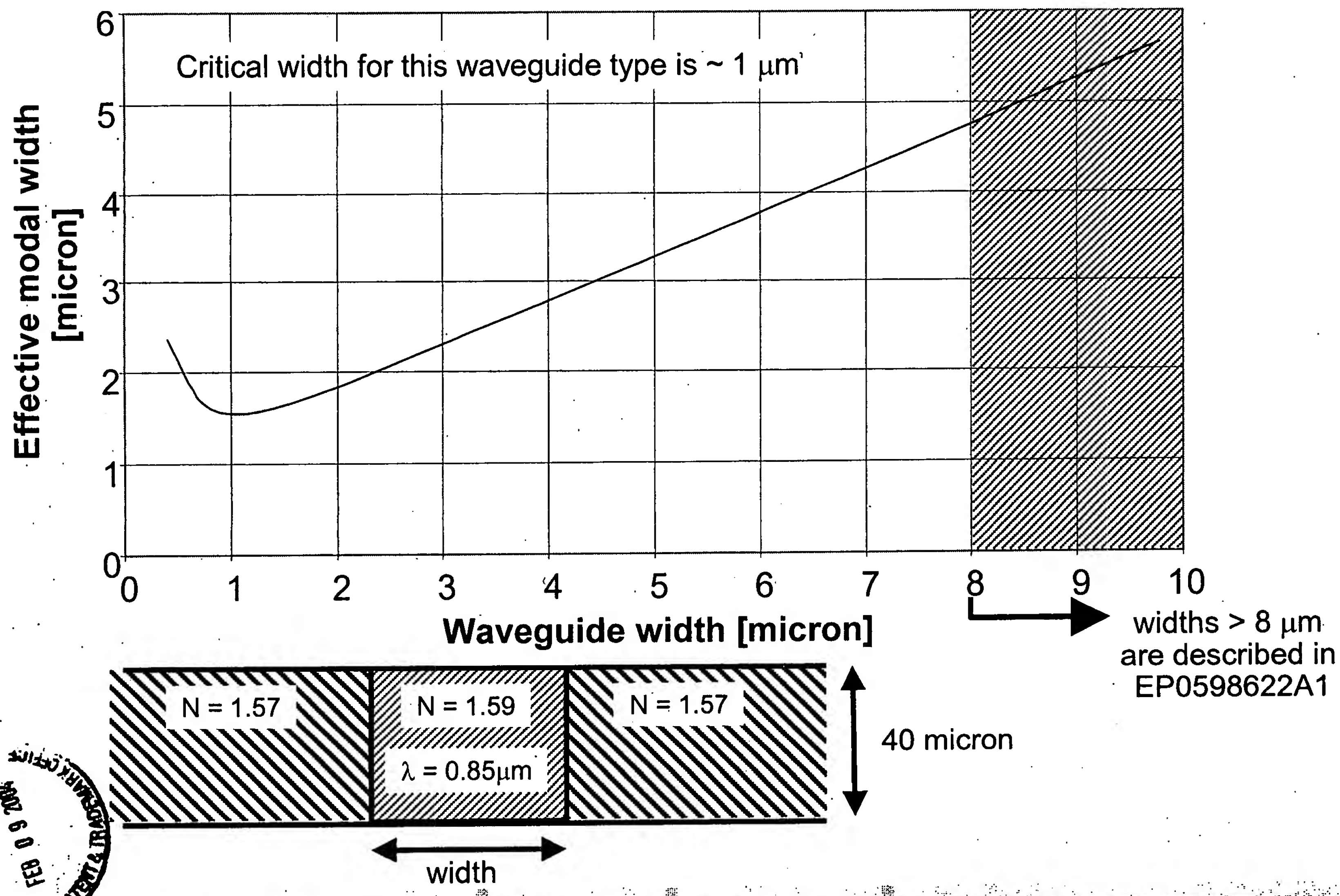
EP 0 598 622 A1, Inventor Arii:
waveguides described are wider than 8 micron, therefore much larger than critical width
Refractive indices and wavelength from patent text, page 6 line 46-47



Conclusion: For large n, the number of additional check bits is $O(n^{1/2})$ compared with $O(t \log n)$ for previous methods.[2,3] Thus, for large n the code construction described is inefficient. It is conjectured that the construction is optimal for $s \leq 2(t+1)$ and close to optimal for $s \leq 3(t+1)$. The construction is valid for all values of s, t and produces some t-EC/AUED codes with $t \geq 2$ which are more efficient than equivalent known codes.[2,3]

Removal of the restriction that the alphabet be limited to symbols containing a single block of adjacent 1s should permit alphabets of greater cardinality than given by eqn. 3 and hence more efficient codes.

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TWO-STEP PURELY THERMAL ION-EXCHANGE TECHNIQUE FOR SINGLE-MODE WAVEGUIDE DEVICES IN GLASS

Indexing terms: Waveguides, Optical waveguide components

Two-step purely thermal ion-exchange technique using two monovalent ions for single-mode waveguides is proposed. Experiments show embedded waveguide structure below the surface of the glass, as computer simulation predicted. The insertion loss of the straight waveguide was less than 1 dB for 19 mm long samples, at both $\lambda = 1.3\,\mu m$ and $1.55\,\mu m$.

Introduction: Single-mode optical devices are prerequisite for high-capacity fibre optic transmission system networking with single-mode fibres (SMFs). Such passive optical components can be fabricated in glass by ion-exchange (I/E) processes. These processes may be divided into two categories depending on whether the I/E is performed in one or two steps, and also on whether the electric field is assisted or not. The two-step I/E process can control waveguide geometry to attain efficient coupling to the SMFs, as well as low propagation loss. The process without the electric field assisted, has been tried with only one monovalent ion (K) and the waveguide structure was the reverse ridge type.[1] An electric field assisted process has been studied with two ions (Cs and Na)[2] and was preferable for the manufacture of embedded waveguides. However, in such a process a special experimental set-up is required, where plus and minus potential salts are kept isolated from each other.

Here we propose a two-step purely thermal I/E process using two monovalent ions. These can fabricate embedded single-mode waveguides, having efficient coupling characteristics to SMFs. The significance of the process is that it is simpler and offers good reproducibility, hence it is suited for high volume production.

Simulation: The proposed process utilises two monovalent ions. Here we denote A ion and B ion which, respectively, increase and decrease the refractive index of the diffused region in glass. The fabrication process is composed of the 1st I/E process through a mask in molten salt which contains the A ion, and the 2nd I/E process through the whole surface of the substrate in another salt, which contains the B ion.

To check the feasibility of the process, computer simulation was carried out to predict the distribution of the ion concentration.[3] The model is based, for simplicity, on the assumption that the A ion and the B ion participate in the I/E process, as monovalent ions. An example of the A ion distribution in the substrate after the process is completed is shown in Fig. 1 in terms of a product of D and t, where D and t are the diffusion constant for the A ion and the I/E process time, respectively.

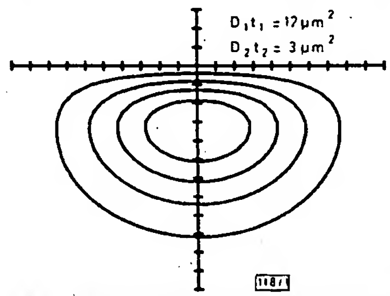

Fig. 1 *A ion concentration distribution by computer simulation after 2nd I/E completed*

Solid lines represent 20%, 40%, 60% and 80% concentration contour. Ion concentration is normalised to 100% at centre, having maximum value. Subscripts 1 and 2 to Dt denote 1st and 2nd I/E processes, respectively

At the appropriate Dt values, waveguides with elliptical cross-section are formed below the surface of the glass. Optimum values for Dt are considered to be around $12\,\mu m^2$ for the 1st I/E process and 0.6–$6\,\mu m^2$ for the 2nd I/E process. One may control the ratio of the horizontal axis to the vertical axis of the waveguide as $1.6:1$ to a value of $1.8:1$, at the 10% contour when the maximum concentration of the A ion after the 1st I/E process is normalised to 100%.

For single-mode operation, we aim to control waveguide parameters in such a way that waveguide diameters come to around $16\,\mu m$ (major diameter) $\times$ $9\,\mu m$ (minor diameter) and the refractive index difference is 0·004. This condition was derived from the V-parameter characteristics for gradient-index elliptical-shaped waveguides in infinite clad.[4]

Fabrication: For the substrate we chose an in-house melted glass of the borosilicate system (SiO_2–B_2O_3–Al_2O_3–$M^{II}O$–Na_2O–K_2O, M^{II} = divalent ion) which has been used for a variety of multimode waveguide devices.[5] Tl ion and Cs ion were tested as the A ions and either one was found to be usable with the K ion as the B ion. Ion exchange was performed at 530°C near the transition temperature of the glass.

In Fig. 2 waveguide cross-sections with different 2nd I/E times are shown. In this experiment we can observe the waveguide shape and dimensions. These samples can guide several

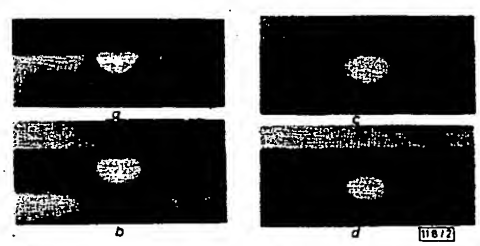

Fig. 2 *Microphotographs of waveguides with different I/E times*

Second I/E times are specified by unit time, t_0
a After first I/E
b After second I/E (second I/E time is $t_2 = t_0$)
c $t_2 = 2t_0$
d $t_2 = 4t_0$

modes at $1{\cdot}3\,\mu m$, and were irradiated with incoherent visible light. It is noted that by increasing the 2nd I/E process time, waveguides become elliptical and get embedded deeper in the substrate.

The refractive index distributions of the waveguides were measured by differential microinterferometry, which were in broad agreement with the simulation results for ion concentration distribution (an example is shown in Fig. 3). The major

Fig. 3 *Differential interference micrograph of waveguide*

diameters of the waveguides were 1·7–1·8 times the minor diameters in length. In contrast with this, the ratios of the major diameter to the minor diameter of the near-field patterns were 1·3–1·6. The mode profiles of the waveguide and a SMF were found to make relatively small difference,[3] indicating that low-loss coupling can be possible.

The insertion losses of the waveguides were measured by inserting waveguides between SMFs having a $10\,\mu m$ mode field diameter and a 0·003 relative refractive index difference. In Tl-doped straight waveguides 19 mm long, the average insertion loss of $1{\cdot}04 \pm 0{\cdot}07$ dB with the minimum loss of 0·94 dB, was attained among 12 samples in a single substrate at a wavelength of $1{\cdot}3\,\mu m$. The loss at $1{\cdot}55\,\mu m$ was $0{\cdot}93 \pm 0{\cdot}11$ dB. Typical coupling loss of the waveguides to SMF was 0·31 dB/connection. Estimated propagation loss of the waveguides was 0·22 dB/cm. The excess losses of the Y-branches were in the range 1·25–1·67 dB. The best branching ratio was better than 49·5 : 50·5 at both $1{\cdot}3\,\mu m$ and $1{\cdot}55\,\mu m$.

The bend losses of the waveguides were also investigated for the wavelength region of 1·2 to $1{\cdot}6\,\mu m$,[6] which is shown in Fig. 4. Four S-shaped waveguides with bend radii of 10 mm to

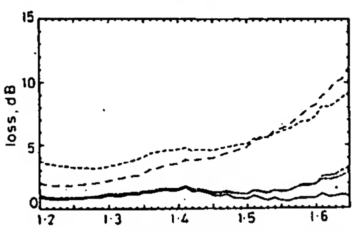

Fig. 4 *Bend losses of S-shaped waveguides against wavelength*

------ R = 10 mm　—·—· R = 40 nm
- - - - R = 15 nm　——— straight
—— R = 40 nm

40 mm and a subtending angle of 10 degrees were under test. It was found that bends do not affect waveguide losses for more than 30 mm radii. However, waveguides with bends of less than 15 mm radii undergo a loss increment and the bend loss increases with increasing wavelength. The results should be taken into account in constructing WDM multiplexers with bent waveguides.[7]

As for polarisation characteristics, depolarisation of guided modes was measured. The extinction ratio of either the TE or the TM mode was more than 26 dB, when the mode was transmitted in the 19 mm samples.

Conclusion: Computer simulation and experiments revealed the feasibility of the 2-step purely thermal ion-exchange process, for low-loss single-mode waveguides. An insertion loss of less than 1 dB was achieved. The technique proposed here is applicable to various passive devices, such as the $N \times M$ coupler that makes use of branching waveguides and/or coupled waveguides.

Acknowledgments: We thank K. Koizumi and Y. Ikeda for their guidance, and E. Okuda and H. Wada for their help with the experiments.

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−70 dBm APD OPTICAL FEEDBACK RECEIVER AT 2·048 Mbit/s

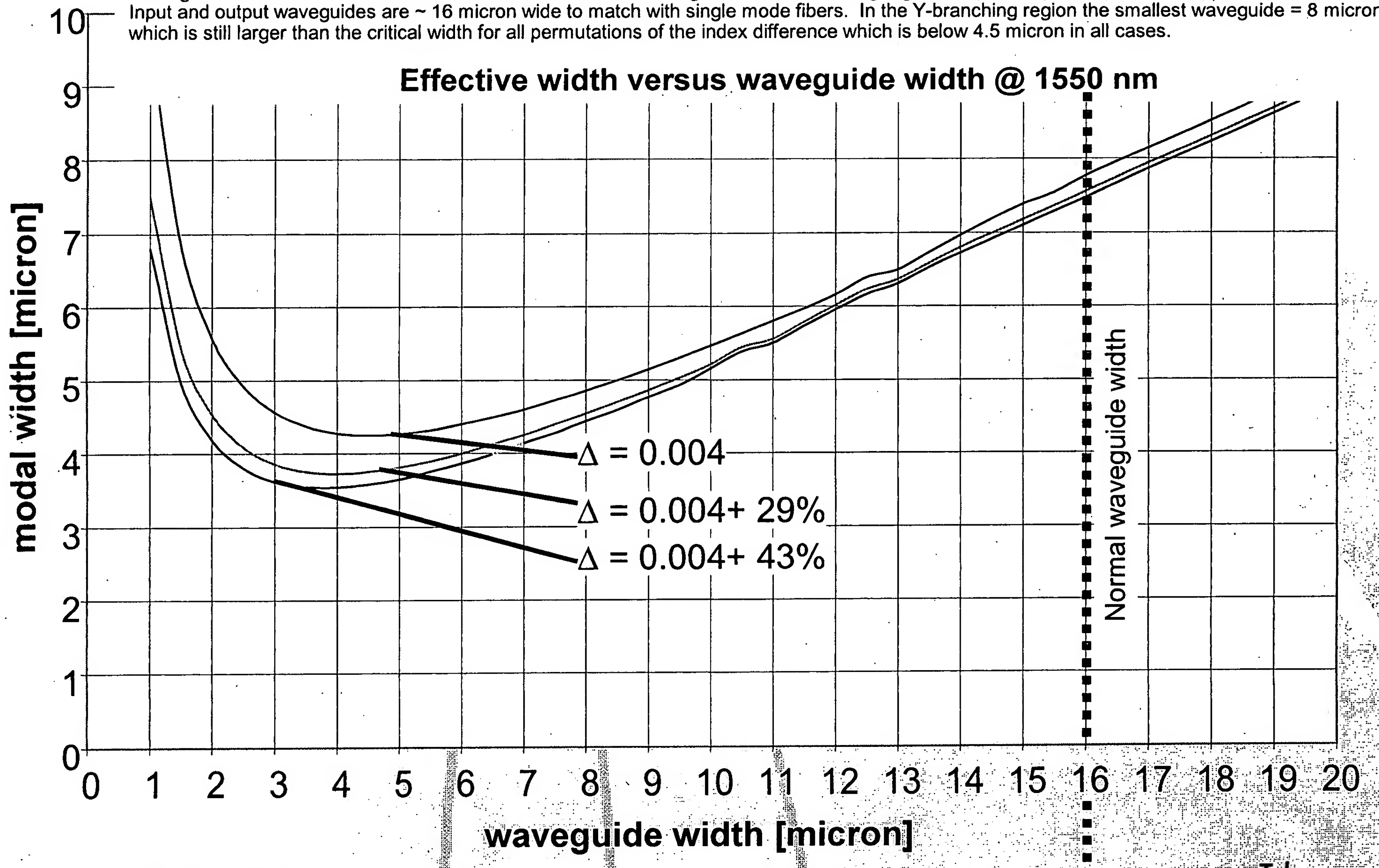
Indexing terms: Optical communications, Optical receivers, Avalanche diodes

We demonstrate an optical feedback (OFB) transimpedance receiver employing a GaInAs avalanche photodiode (APD) input device and an Si *pin* diode feedback element. The highest reported sensitivity of −70 dBm at 2·048 Mbit/s was achieved.

Introduction: OFB optical receivers have recently demonstrated enhanced sensitivity over conventional resistive designs for low-bit-rate (1–2 Mbit/s) optical communication systems.[1–3] These receivers have used a pair of *pin* diodes as the input devices, one accepting the main optical input and one accepting optical feedback from a light source driven by the output. With feedback resistor noise and parasitics thereby absent, *pin* diode shot noise is typically the dominant noise source in these receivers. Good results thus demand low-leakage devices, and a sensitivity of −64 dBm at 2·048 Mbit/s is presently the highest reported for a *pin* receiver.[2,3] The reduction in leakage currents of latest generation GaInAs APDs has now allowed them to be considered for use in high-performance OFB receivers.

Theory of APD-pin OFB receiver: Fig. 1 shows the circuit topology of the APD-*pin* OFB receiver. Input noise sources consist of FET, *pin* and APD. FET noise consists of gate shot

Glass Waveguide 1xN branching devices, Tanaka et. al:
indices and wavelength from article Electronics Letters, Vol 24. No 20, 29 September 1988, Seki, Hashizume et al, Nippon Sheet Glass
"Two-step purely thermal ion-exchange technique for single mode waveguide devices in glass"
waveguides described have an index contrast of $\Delta = 0.004$, or larger in the Y-branching region, respectively 43% (worst case) and 29% best case.
Input and output waveguides are ~ 16 micron wide to match with single mode fibers. In the Y-branching region the smallest waveguide = 8 micron, which is still larger than the critical width for all permutations of the index difference which is below 4.5 micron in all cases.



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"Two-step purely thermal ion-exchange technique for single mode waveguide devices in glass"
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